

APPARATUS, AND ASSOCIATED METHOD, FOR
SELECTING A SWITCHING THRESHOLD FOR A
TRANSMITTER UTILIZING ADAPTIVE MODULATION TECHNIQUES

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a Continuation-in-Part to co-pending United States Application Number 09/751,640, filed on December 29, 2000, and claims benefit of Provisional Application Serial Number 60/250,242, filed on November 30, 2000, assigned to assignee of present application and incorporated herein by reference.

10

15

20

The present invention relates generally to a manner by which to select a modulation parameter at a sending station, such as the transmit portion of a base transceiver station or mobile station operable in a cellular communication system, which uses adaptive modulation techniques. More particularly, the present invention relates to apparatus, and an associated method, for dynamically selecting a switching threshold used in the selection of the modulation parameter. The switching threshold is selected responsive to a constrained optimization scheme in which two, or more, communication characteristics defining performance criteria are used in the selection of the switching threshold. Selection is made, for example, to optimize one of the communication

characteristics while also ensuring that at least one additional communication characteristic is at least fulfilled, i.e., of an acceptable level. By dynamically selecting the switching threshold upon two or more performance criteria, improved quality levels of communication are possible as additional performance criteria are used in the selection of the switching threshold and, hence, determination of the modulation parameter which is used.

BACKGROUND OF THE INVENTION

The use of wireless communication systems through which to communicate has achieved wide popularity in recent years. In a wireless communication system, a radio link is utilized upon which to form a communication path between a sending station and a receiving station. In contrast to a conventional, wireline communication system which requires fixed, wired connections to be maintained between the sending and receiving stations, use of a wireless communication system inherently permits increased mobility of communication. Additionally, infrastructure costs associated with a wireless communication system are generally less than the corresponding costs associated with the infrastructure of a conventional, wireline communication system.

Installation of a wireless communication system is therefore generally less costly than the costs associated with installation of a wireline communication system.

Multi-user, wireless communication systems permit relatively 5 large numbers of users simultaneously to communicate by way of such systems. A cellular communication system is exemplary of a wireless, multi-user, radio communication system which has been installed over significant geographical areas and which has achieved wide levels of usage.

A cellular communication system makes relatively efficient use of the portion of the electromagnetic spectrum allocated thereto upon which to define communication channels. The infrastructure of a cellular communication system includes a plurality of fixed-site base stations which are installed at spaced-apart locations throughout a geographical area. Because of the positioning of the base stations, only relatively low power signals are needed to be transmitted to effectuate communications with a mobile station. By transmitting relatively low-power signals, the same frequencies can be reused at 20 different locations throughout the geographical area in which the network infrastructure installed. Communications can be effectuated between more than one set of sending and receiving

stations concurrently at separate locations throughout the area encompassed by the cellular communication system.

In an ideal communication system, data, communicated by the sending station, is communicated distortion-free upon a communication channel to the receiving station. When the data is received at the receiving station, the data is substantially identical in value to the corresponding data when transmitted by the sending station. However, in a non ideal communication system in which the data is communicated upon a non ideal communication channel, the data, when received at the receiving station, is dissimilar to the corresponding values of the data when sent by the sending station. Distortion of the data caused by transmission of the data upon the non ideal communication channel causes such dissimilarities to result. If the distortion is significant, the informational content of the signal cannot be recovered at the receiving station.

The communication channel might be of characteristics which distort the value of the information bearing bits forming the data which is communicated upon the communication channel to the receiving station. Fading, such as that caused by multi-path transmission or Rayleigh fading, alters the data during its transmission. Such distortion, if not corrected, reduces the

communication quality levels in a communication session formed between the sending and the receiving stations.

Various techniques are utilized to overcome distortion introduced upon the data as a result of transmission upon a non ideal communication channel.

Time-encoding of the data, prior to its transmission, for instance, increases the redundancy of the transmitted data. By increasing the time redundancy of the data, the likelihood of the informational content of the data being recoverable, once received at the receiving station, is increased. Increasing the time redundancy of the data is sometimes referred to as creating time diversity.

Adaptive modulation is also sometimes utilized. In an adaptive modulation technique, the manner by which the data is modulated is selected responsive to the channel conditions of the communication channel upon which the data is to be communicated. That is to say, the modulation scheme utilized by which to modulate the data is selected according to the channel conditions. High-order modulations are utilized with little, or no, coding when the channel conditions are good. Conversely, low-order modulation schemes with maximum coding are utilized when the channel conditions are poor. Determination of the

channel conditions are made through, for instance, evaluation of measured signal-to-noise ratios (SNRs).

The range of possible values of the SNR is partitioned into a number of fading regions. A specific modulation scheme or a 5 specific coding scheme, or a combination of both, is assigned to each region. Selection of the boundaries between regions is important as the boundaries define which modulation and/or coding schemes are utilized to overcome the non ideal channel conditions. The region boundaries shall herein be referred to as switching thresholds as switching between modulation parameters such as the modulation-type and coding-type switch at such boundaries.

In the aforementioned co-pending patent application of Serial No. 09/751,640, an artificial intelligence learning scheme is utilized to optimize the switching thresholds so as to maximize the data throughput (TP) of the communication of the data from the sending station to the receiving station. With further communication of the data, the long-term data throughput is continuously monitored and values derived therefrom are used 20 as a referee to train the artificial intelligence learning scheme. A manner is thereby disclosed by which to facilitate maximization of data throughput upon a non ideal communication channel.

The use of additional performance criteria, in addition to data throughput, might additionally be utilized in the selection of switching thresholds.

5 It is in light of this background information related to communication systems which utilize adaptive modulation schemes that the significant improvements of the present invention have evolved.

SUMMARY OF THE INVENTION

The present invention, accordingly, advantageously provides apparatus, and an associated method, by which to facilitate selection of a modulation parameter by which to operate upon data to be communicated by a sending station which utilizes adaptive modulation techniques.

Through operation of an embodiment of the present invention, dynamic selection of a switching threshold is performed. The switching threshold is used to end the selection of the modulation parameter as the switching threshold defines the boundaries between regions at which different modulation
20 parameters are utilized.

The switching threshold is selected responsive to a constrained optimization scheme in which two, or more,

5

performance criteria defined of communication characteristics are used in the selection of the switching threshold. Selection is made, e.g., to optimize one of the communication characteristics while also ensuring that at least one additional communication characteristic is at least fulfilled.

Dynamic selection of the switching threshold permits corresponding dynamic selection of a modulation parameter by which to operate upon data pursuant to an adaptive modulation technique. Improved quality of communications is facilitated as a result of the dynamic selection process. And, as the switching threshold is selected responsive to satisfaction of multiple performance criteria, a constrained optimization criteria facilitates further improved communication quality levels of communications.

Quality of service levels are, of course, dependent upon many criteria, and satisfaction of additional performance criteria are often needed in order to satisfy a particular quality of service level.

Implementation of an embodiment of the present invention 20 utilizes, for instance, stochastic computing elements, formed of basic logic gates. Other synthesis automata can alternately be utilized. Implementation is effectuated at a transmitter as part of an adaptive modulation selector.

In another aspect of the present invention, the constrained optimization of the performance criteria optimizes throughput (TP) while maintaining an error rate indicia within an allowable level. As the throughput and error rate indicia changes, the 5 constrained optimization scheme results in alteration of the threshold level used to select the modulation parameter upon which data is operated.

In another aspect of the present invention, an enhanced linear-reward-inaction (LRI) learning algorithm is provided and used to provide an adaptive switching threshold to be used in the selection of a modulation parameter, such as a modulation-type or an encoding complexity level. The enhanced LRI learning algorithm is coupled to receive indicia representative of an error rate indicia and a throughput indicia and utilizes such values as a joint referee for the enhanced LRI learning algorithm.

More than one adaptive switching thresholds are determinable. Each of the separate switching thresholds defines a boundary region defining different modulation parameters. 20 Thereby, an adaptive modulation scheme can utilize, selectively, several different modulation parameters depending upon communication characteristics of a communication channel upon which data is to be communicated. When communication conditions

worsen, the modulation parameter is selectively changed so that the data is better able to be communicated upon the communication channel in a manner to permit its subsequent recovery at a receiving station which receives the communicated data.

5 Conversely, when the communication conditions upon the communication channel improve, the modulation parameters are selectively altered, responsive to positioning upon one, or the other, side of a switching threshold, thereby to improve the rate at which the data is communicated. Because the switching thresholds are adaptively selected responsive to communication characteristics of the communication channel, as communication conditions change, the switching threshold is adaptively altered, thereby to permit redefinition of the region boundaries.

In another aspect of the present invention, signal-to-noise ratios (SNRs) of data communicated upon a communication channel are determined, and the switching thresholds are defined in terms of SNR values. Adaptive alteration of the switching threshold is made responsive to the evaluation of the constrained optimization parameters. As indicated SNR values change, the modulation 20 parameter is correspondingly changed. Thereby, as the communication characteristics, indicated by the measured SNR values, change, the complexities of the operations performed upon the data are selectively altered.

In one implementation, a manner is provided by which to facilitate selection of a switching threshold used pursuant to operation of an adaptive modulation selector of a base transceiver station operable in a cellular communication system.

5 Implementation is permitted, e.g., in any of various, proposed 3G (Third Generation), such as a CDMA 2000 system which provides for 1XTREME data communications. The selected threshold level is adaptively determined, defined in terms of an SNR value. Two, or more, communication characteristics defining performance criteria are utilized in the determination of the switching threshold level. Constrained optimization is performed by which to maximize throughput while maintaining a frame error rate (FER) within a permissible level. The throughput and FER values are feedback, or other measured, values. Thereby, the level of the switching threshold determined responsive to the constrained optimization evaluation is dynamically determinable. Subsequent selection of the modulation parameter to be utilized by which to operate upon the data to be communicated is thereby better selectable responsive to actual communication performance.

20 In these and other aspects, therefore, apparatus, and an associated method, is provided for a communication system having a first communication station operable to transmit data upon a communication channel susceptible to fading. Dynamic selection

5

of at least a first switching threshold used in selection of a modulation parameter is made. A calculator is coupled to receive indications of a selected communication indicia associated with communication characteristics of the communication channel during a selected interval. The calculator selects the at least the first switching threshold. The first switching threshold is selected by the calculator to at least satisfy a first performance criteria and also to satisfy at least a second performance criteria.

A more complete appreciation of the present invention and the scope thereof can be obtained from the accompanying drawings which are briefly summarized below, the detailed description of the presently preferred embodiments of the invention, and the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 illustrates a functional block diagram of a communication system in which an embodiment of the present invention is operable.

Figure 2 illustrates a graphical representation of several exemplary, adaptive switching thresholds selected during operation of an embodiment of the present invention and utilized

in the selection of a modulation parameter at the communication station forming a portion of the communication system shown in Figure 1.

Figure 3 illustrates a graphical representation of exemplary throughput (TP), frame error rate (FER) and frames per burst (FPB) values plotted as functions of an exemplary switching threshold.

Figure 4 illustrates a method flow diagram listing the method steps of the method of operation of an embodiment of the present invention.

DETAILED DESCRIPTION

Referring first to Figure 1, a communication system, shown generally at 10, provides for radio communications with a mobile station, such as the mobile station 12. In the exemplary implementation, the communication system is representative of any of various, proposed 3G (Third Generation) cellular communication systems, such as a CDMA2000 system which provides for 1XTREME data communications. The communication system is also representative of any of many other types of communication systems. While the following description shall describe operation of the communication system 10 with respect to its

exemplary implementation as a 3G cellular communication system, in other implementations, operation of an embodiment of the present invention can analogously be described with respect to its implementation in another type of communication system. And, 5 while operation of an embodiment of the present invention is described with respect to communications in a downlink direction, i.e., to the mobile station, operation of an embodiment of the present invention is analogously also operable in an uplink direction , i.e., from the mobile station.

10
00
50
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
185
190
195
200
205
210
215
220
225
230
235
240
245
250
255
260
265
270
275
280
285
290
295
300
305
310
315
320
325
330
335
340
345
350
355
360
365
370
375
380
385
390
395
400
405
410
415
420
425
430
435
440
445
450
455
460
465
470
475
480
485
490
495
500
505
510
515
520
525
530
535
540
545
550
555
560
565
570
575
580
585
590
595
600
605
610
615
620
625
630
635
640
645
650
655
660
665
670
675
680
685
690
695
700
705
710
715
720
725
730
735
740
745
750
755
760
765
770
775
780
785
790
795
800
805
810
815
820
825
830
835
840
845
850
855
860
865
870
875
880
885
890
895
900
905
910
915
920
925
930
935
940
945
950
955
960
965
970
975
980
985
990
995
1000
1005
1010
1015
1020
1025
1030
1035
1040
1045
1050
1055
1060
1065
1070
1075
1080
1085
1090
1095
1100
1105
1110
1115
1120
1125
1130
1135
1140
1145
1150
1155
1160
1165
1170
1175
1180
1185
1190
1195
1200
1205
1210
1215
1220
1225
1230
1235
1240
1245
1250
1255
1260
1265
1270
1275
1280
1285
1290
1295
1300
1305
1310
1315
1320
1325
1330
1335
1340
1345
1350
1355
1360
1365
1370
1375
1380
1385
1390
1395
1400
1405
1410
1415
1420
1425
1430
1435
1440
1445
1450
1455
1460
1465
1470
1475
1480
1485
1490
1495
1500
1505
1510
1515
1520
1525
1530
1535
1540
1545
1550
1555
1560
1565
1570
1575
1580
1585
1590
1595
1600
1605
1610
1615
1620
1625
1630
1635
1640
1645
1650
1655
1660
1665
1670
1675
1680
1685
1690
1695
1700
1705
1710
1715
1720
1725
1730
1735
1740
1745
1750
1755
1760
1765
1770
1775
1780
1785
1790
1795
1800
1805
1810
1815
1820
1825
1830
1835
1840
1845
1850
1855
1860
1865
1870
1875
1880
1885
1890
1895
1900
1905
1910
1915
1920
1925
1930
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050
2055
2060
2065
2070
2075
2080
2085
2090
2095
2100
2105
2110
2115
2120
2125
2130
2135
2140
2145
2150
2155
2160
2165
2170
2175
2180
2185
2190
2195
2200
2205
2210
2215
2220
2225
2230
2235
2240
2245
2250
2255
2260
2265
2270
2275
2280
2285
2290
2295
2300
2305
2310
2315
2320
2325
2330
2335
2340
2345
2350
2355
2360
2365
2370
2375
2380
2385
2390
2395
2400
2405
2410
2415
2420
2425
2430
2435
2440
2445
2450
2455
2460
2465
2470
2475
2480
2485
2490
2495
2500
2505
2510
2515
2520
2525
2530
2535
2540
2545
2550
2555
2560
2565
2570
2575
2580
2585
2590
2595
2600
2605
2610
2615
2620
2625
2630
2635
2640
2645
2650
2655
2660
2665
2670
2675
2680
2685
2690
2695
2700
2705
2710
2715
2720
2725
2730
2735
2740
2745
2750
2755
2760
2765
2770
2775
2780
2785
2790
2795
2800
2805
2810
2815
2820
2825
2830
2835
2840
2845
2850
2855
2860
2865
2870
2875
2880
2885
2890
2895
2900
2905
2910
2915
2920
2925
2930
2935
2940
2945
2950
2955
2960
2965
2970
2975
2980
2985
2990
2995
3000
3005
3010
3015
3020
3025
3030
3035
3040
3045
3050
3055
3060
3065
3070
3075
3080
3085
3090
3095
3100
3105
3110
3115
3120
3125
3130
3135
3140
3145
3150
3155
3160
3165
3170
3175
3180
3185
3190
3195
3200
3205
3210
3215
3220
3225
3230
3235
3240
3245
3250
3255
3260
3265
3270
3275
3280
3285
3290
3295
3300
3305
3310
3315
3320
3325
3330
3335
3340
3345
3350
3355
3360
3365
3370
3375
3380
3385
3390
3395
3400
3405
3410
3415
3420
3425
3430
3435
3440
3445
3450
3455
3460
3465
3470
3475
3480
3485
3490
3495
3500
3505
3510
3515
3520
3525
3530
3535
3540
3545
3550
3555
3560
3565
3570
3575
3580
3585
3590
3595
3600
3605
3610
3615
3620
3625
3630
3635
3640
3645
3650
3655
3660
3665
3670
3675
3680
3685
3690
3695
3700
3705
3710
3715
3720
3725
3730
3735
3740
3745
3750
3755
3760
3765
3770
3775
3780
3785
3790
3795
3800
3805
3810
3815
3820
3825
3830
3835
3840
3845
3850
3855
3860
3865
3870
3875
3880
3885
3890
3895
3900
3905
3910
3915
3920
3925
3930
3935
3940
3945
3950
3955
3960
3965
3970
3975
3980
3985
3990
3995
4000
4005
4010
4015
4020
4025
4030
4035
4040
4045
4050
4055
4060
4065
4070
4075
4080
4085
4090
4095
4100
4105
4110
4115
4120
4125
4130
4135
4140
4145
4150
4155
4160
4165
4170
4175
4180
4185
4190
4195
4200
4205
4210
4215
4220
4225
4230
4235
4240
4245
4250
4255
4260
4265
4270
4275
4280
4285
4290
4295
4300
4305
4310
4315
4320
4325
4330
4335
4340
4345
4350
4355
4360
4365
4370
4375
4380
4385
4390
4395
4400
4405
4410
4415
4420
4425
4430
4435
4440
4445
4450
4455
4460
4465
4470
4475
4480
4485
4490
4495
4500
4505
4510
4515
4520
4525
4530
4535
4540
4545
4550
4555
4560
4565
4570
4575
4580
4585
4590
4595
4600
4605
4610
4615
4620
4625
4630
4635
4640
4645
4650
4655
4660
4665
4670
4675
4680
4685
4690
4695
4700
4705
4710
4715
4720
4725
4730
4735
4740
4745
4750
4755
4760
4765
4770
4775
4780
4785
4790
4795
4800
4805
4810
4815
4820
4825
4830
4835
4840
4845
4850
4855
4860
4865
4870
4875
4880
4885
4890
4895
4900
4905
4910
4915
4920
4925
4930
4935
4940
4945
4950
4955
4960
4965
4970
4975
4980
4985
4990
4995
5000
5005
5010
5015
5020
5025
5030
5035
5040
5045
5050
5055
5060
5065
5070
5075
5080
5085
5090
5095
5100
5105
5110
5115
5120
5125
5130
5135
5140
5145
5150
5155
5160
5165
5170
5175
5180
5185
5190
5195
5200
5205
5210
5215
5220
5225
5230
5235
5240
5245
5250
5255
5260
5265
5270
5275
5280
5285
5290
5295
5300
5305
5310
5315
5320
5325
5330
5335
5340
5345
5350
5355
5360
5365
5370
5375
5380
5385
5390
5395
5400
5405
5410
5415
5420
5425
5430
5435
5440
5445
5450
5455
5460
5465
5470
5475
5480
5485
5490
5495
5500
5505
5510
5515
5520
5525
5530
5535
5540
5545
5550
5555
5560
5565
5570
5575
5580
5585
5590
5595
5600
5605
5610
5615
5620
5625
5630
5635
5640
5645
5650
5655
5660
5665
5670
5675
5680
5685
5690
5695
5700
5705
5710
5715
5720
5725
5730
5735
5740
5745
5750
5755
5760
5765
5770
5775
5780
5785
5790
5795
5800
5805
5810
5815
5820
5825
5830
5835
5840
5845
5850
5855
5860
5865
5870
5875
5880
5885
5890
5895
5900
5905
5910
5915
5920
5925
5930
5935
5940
5945
5950
5955
5960
5965
5970
5975
5980
5985
5990
5995
6000
6005
6010
6015
6020
6025
6030
6035
6040
6045
6050
6055
6060
6065
6070
6075
6080
6085
6090
6095
6100
6105
6110
6115
6120
6125
6130
6135
6140
6145
6150
6155
6160
6165
6170
6175
6180
6185
6190
6195
6200
6205
6210
6215
6220
6225
6230
6235
6240
6245
6250
6255
6260
6265
6270
6275
6280
6285
6290
6295
6300
6305
6310
6315
6320
6325
6330
6335
6340
6345
6350
6355
6360
6365
6370
6375
6380
6385
6390
6395
6400
6405
6410
6415
6420
6425
6430
6435
6440
6445
6450
6455
6460
6465
6470
6475
6480
6485
6490
6495
6500
6505
6510
6515
6520
6525
6530
6535
6540
6545
6550
6555
6560
6565
6570
6575
6580
6585
6590
6595
6600
6605
6610
6615
6620
6625
6630
6635
6640
6645
6650
6655
6660
6665
6670
6675
6680
6685
6690
6695
6700
6705
6710
6715
6720
6725
6730
6735
6740
6745
6750
6755
6760
6765
6770
6775
6780
6785
6790
6795
6800
6805
6810
6815
6820
6825
6830
6835
6840
6845
6850
6855
6860
6865
6870
6875
6880
6885
6890
6895
6900
6905
6910
6915
6920
6925
6930
6935
6940
6945
6950
6955
6960
6965
6970
6975
6980
6985
6990
6995
7000
7005
7010
7015
7020
7025
7030
7035
7040
7045
7050
7055
7060
7065
7070
7075
7080
7085
7090
7095
7100
7105
7110
7115
7120
7125
7130
7135
7140
7145
7150
7155
7160
7165
7170
7175
7180
7185
7190
7195
7200
7205
7210
7215
7220
7225
7230
7235
7240
7245
7250
7255
7260
7265
7270
7275
7280
7285
7290
7295
7300
7305
7310
7315
7320
7325
7330
7335
7340
7345
7350
7355
7360
7365
7370
7375
7380
7385
7390
7395
7400
7405
7410
7415
7420
7425
7430
7435
7440
7445
7450
7455
7460
7465
7470
7475
7480
7485
7490
7495
7500
7505
7510
7515
7520
7525
7530
7535
7540
7545
7550
7555
7560
7565
7570
7575
7580
7585
7590
7595
7600
7605
7610
7615
7620
7625
7630
7635
7640
7645
7650
7655
7660
7665
7670
7675
7680
7685
7690
7695
7700
7705
7710
7715
7720
7725
7730
7735
7740
7745
7750
7755
7760
7765
7770
7775
7780
7785
7790
7795
7800
7805
7810
7815
7820
7825
7830
7835
7840
7845
7850
7855
7860
7865
7870
7875
7880
7885
7890
7895
7900
7905
7910
7915
7920
7925
7930
7935
7940
7945
7950
7955
7960
7965
7970
7975
7980
7985
7990
7995
8000
8005
8010
8015
8020
8025
8030
8035
8040
8045
8050
8055
8060
8065
8070
8075
8080
8085
8090
8095
8100
8105
8110
8115
8120
8125
8130
8135
8140
8145
8150
8155
8160
8165
8170
8175
8180
8185
8190
8195
8200
8205
8210
8215
8220
8225
8230
8235
8240
8245
8250
8255
8260
8265
8270
8275
8280
8285
8290
8295
8300
8305
8310
8315
8320
8325
8330
8335
8340
8345
8350
8355
8360
8365
8370
8375
8380
8385
8390
8395
8400
8405
8410
8415
8420
8425
8430
8435
8440
8445
8450
8455
8460
8465
8470
8475
8480
8485
8490
8495
8500
8505
8510
8515
8520
8525
8530
8535
8540
8545
8550
8555
8560
8565
8570
8575
8580
8585
8590
8595
8600
8605
8610
8615
8620
8625
8630
8635
8640
8645
8650
8655
8660
8665
8670
8675
8680
8685
8690
8695
8700
8705
8710
8715
8720
8725
8730
8735
8740
8745
8750
8755
8760
8765
8770
8775
8780
8785
8790
8795
8800
8805
8810
8815
8820
8825
8830
8835
8840
8845
8850
8855
8860
8865
8870
8875
8880
8885
8890
8895
8900
8905
8910
8915
8920
8925
8930
8935
8940
8945
8950
8955
8960
8965
8970
8975
8980
8985
8990
8995
9000
9005
9010
9015
9020
9025
9030
9035
9040
9045
9050
9055
9060
9065
9070
9075
9080
9085
9090
9095
9100
9105
9110
9115
9120
9125
9130
9135
9140
9145
9150
9155
9160
9165
9170
9175
9180
9185
9190
9195
9200
9205
9210
9215
9220
9225
9230
9235
9240
9245
9250
9255
9260
9265
9270
9275
9280
9285
9290
9295
9300
9305
9310
9315
9320
9325
9330
9335
9340
9345
9350
9355
9360
9365
9370
9375
9380
9385
9390
9395
9400
9405
9410
9415
9420
9425
9430
9435
9440
9445
9450
9455
9460
9465
9470
9475
9480
948

network includes other functional entities, here including a radio network controller (RNC) 22.

The radio access network is, in turn, coupled to a packet data network (PDN) 26, such as the Internet backbone, by way of a gateway (GWY) 28. A correspondent device, here represented by a data source 32 is connected to the packet data network, and a communication path is formable between the correspondent device and the mobile station by way of the network portion of the communication system and the radio link 16. In the exemplary implementation, the data communicated with the communication station is frame-formatted, and communication of the data is effectuated by communicating successive frames between the correspondent device formed of the data source and the mobile station.

The base transceiver station 14 includes a receive portion 36 and a transmit portion 38. The transmit portion is here shown to include an encoder 42, a modulator 44, and an up-converter/amplifier 46. Data to be communicated by the base transceiver station upon the radio link 16 is encoded by the encoder at a selected encoding rate, and the encoded data is modulated by the modulator by a selected modulation technique. Thereafter, the encoded and modulated data is up-converted and amplified by the up-converter and amplifier and provided to an

antenna transducer 48 to be transduced thereat and communicated by way of the radio link to the mobile station. Data communicated by the base transceiver station to the mobile station is referred to as being generated in the downlink direction, and data originated at the mobile station and transmitted to the base transceiver station is referred to as being transmitted in the reverse link direction. Reverse-link data sent by the mobile station to the base transceiver station is detected at the antenna transducer 48, transduced into electrical form and provided to the receive portion 36 to be operated upon thereat.

The base transceiver station 14 also includes a control portion 52. The control portion is coupled to both the receive and transmit portions of the base transceiver station. The control portion includes an adaptive modulator 54 which selects one or more modulation parameters determinative of the manner by which the transmit portion 38 of the base transceiver station operates upon the data which is to be transmitted therefrom. The lines 56 and 58 extending to the encoder and to the modulator, respectively, are representative of indications of selected encoding rates and indications of selected modulation-types by which the encoder and modulator, respectively, are selected by the adaptive modulator to be operable.

The control portion 52 further includes an enhanced linear-reward-inaction (LRI) learning algorithm element 56 operable to perform calculations, indicated by the calculation function 58 pursuant to an embodiment of the present invention. The enhanced 5 LRI function is coupled to receive inputs, here an indication of a data throughput (TP) on the line 62 and an indication of the frame error rate (FER) on the line 64. The TP and FER values are representative of measured, or calculated, communication characteristics of the communication of data upon the radio link 16. Here, the lines 62 and 64 extend from the receive portion 36 as the TP and FER values are determined at, or provided responsive to information supplied by, the mobile station 12.

The mobile station 12 also includes receive and transmit portions, here designated by the portions 68 and 72. The receive portion 68 is shown also to include a demodulator 74 and a decoder 76. A control portion 78 is coupled between the receive and transmit portions 68 and 72. When data frames are received at the mobile station, the control portion, amongst other things, operates to determine the number of frames which are in error. 20 Such determinations are made, for instance, through CRC (cyclic redundancy check) evaluations. Throughput is also determinable by the control portion. Determinations made by the control

portion are provided to the transmit portion and returned by way of a reverse link communication to the base transceiver station.

When detected by the receive portion 36 of the base transceiver station, such information is extracted and provided 5 to the enhanced LRI function 56. Calculations are performed by the calculator 58 to determine a switching threshold value. In one implementation, several switching threshold levels are calculated. The switching level thresholds are calculated according to a constrained optimization scheme. In the exemplary implementation, the constrained optimization scheme selects a switching threshold level to maximize throughput while maintaining the frame error rate with selected levels. As the values of TP and FER change, the value of the switching threshold level also changes in conformity with compliance with the constrained optimization scheme. Thereby, the switching threshold level is adaptively determined.

Indications of the selected switching threshold levels are provided to the adaptive modulator, here by way of the line 82. The adaptive modulator makes use of the switching threshold level 20 to determine the modulation parameter, or parameters, generated on the lines 56 and 58. As the switching threshold level is adaptively alterable, the modulation parameters selected by the adaptive modulator correspondingly are adaptively alterable.

Thereby, depending upon the communication conditions upon the radio link 16, the modulation parameters are better selected to facilitate the best level of communications, i.e., the highest throughput levels while maintaining frame error rates within acceptable levels.

The adaptive modulator 54 is coupled to receive indications of an SNR value, here applied by way of the line 84. The SNR value is compared together with the switching threshold level and, responsive to the comparison, the adaptive modulator selects the modulation parameters to be used by the transmit portion 38 of the base transceiver station.

卷之三

20

Figure 2 illustrates a graphical representation, shown generally at 92 representative of exemplary operation of the enhanced LRI function and adaptive modulator forming a portion of the communication system shown in Figure 1. Here, three switching threshold levels, switching threshold level 94, switching threshold level 96, and switching threshold level 98, are plotted along an SNR axis 102. The switching threshold levels define separate regions, here regions 102, 104, and 106 bounded by the switching threshold levels. Each of the regions 102, 104, and 106 have associated therewith modulation parameters. When an SNR value is applied to the adaptive modulator by way of the line 84 (shown in Figure 1), the region

associated with the SNR value is determinative of the modulation parameter by which the data is operated upon by the transmit portion of the base transceiver station.

Arrows 108 positioned beneath the switching threshold levels 5 94, 96, and 98 are representative of the adaptive nature of the switching thresholds. As the switching thresholds are determined responsive to a constrained optimization scheme, the values of the switching threshold levels are correspondingly altered together with changes in the parameters which define the constrained optimization scheme. By changing the values of the switching threshold levels, the boundaries which define respective ones of the regions 102, 104, and 106 are correspondingly altered. As the adaptive modulator 54 (shown in Figure 1) selects modulation parameters responsive to in which region that the SNR value of data communicated upon the communication channel falls, the modulation parameters selected by the adaptive modulator are also dependent upon the defined regions, as set by the switching threshold levels.

Figure 3 illustrates a graphical representation, shown 20 generally at 112, representative of the relationship between a data throughput (TP) rate and a switching threshold level. Here, normalized values of the throughput are plotted as a function of a switching threshold level value to form the curve 114,

normalized frame error rates are plotted as a function of the switching threshold value to form the curve 116, and normalized values of frames per burst are plotted as a function of switching threshold levels to form the curve 118. The throughput is
5 defined as: $TP = (1-FER) * FPB$.

Analysis of the curves 114, 116, and 118 indicates that the respective TP, FER, and FPB values are dependent upon the level of the switching threshold. That is to say, as the level of the switching threshold changes, i.e., is adaptively altered responsive to maintenance of a constrained optimization scheme, the resulting values of TP, FER, and FPB change.

For instance, when the level of the switching threshold is low, large values of FER are exhibited. And, as the level of the switching threshold increases, the value of the FER decreases.

In exemplary implementation, the encoder 42 of the transmit portion 38 of the base transceiver station shown in Figure 1 exhibits a constraint length of $K = 9$ and an encoding rate $R = \frac{2}{3}$. A data frame communicated by the base transceiver station is of a 184 bit length, adding eight tailing bits such that an encoded
20 frame is of a 384 symbol length. The modulator 44 in the exemplary implementation modulates the encoded data applied thereto using either QPSK, 16 QAM, or 64 QAM modulation techniques. Hence, during a frame burst, either one, two, three

frames of data are sent upon the radio link, depending upon which of the modulation schemes are utilized.

The adaptive modulator 54 monitors instantaneous fading channel gain of the radio link 16 at the beginning of each frame 5 burst and also the number of error frames in a preceding burst. The number of error frames in the preceding burst is used in conjunction with the number of frames transmitted to estimate the frame error rate, the frames transmitted per burst, and the throughput. The modulator 54 selects the appropriate modulation scheme in a frame burst-by-frame burst basis according to the instantaneous channel gain, so as to maximize the long term average TP subject to a target FER limit.

Further, with respect to the switching threshold levels selected by the enhanced LRI function, three switching threshold levels are determined. The switching threshold levels define, therefore, a first region 102 extending between no transmission to QPSK modulation, a second region 104 extending between QPSK and 16 QAM modulation, and a third region 106 defining 16 QAM modulation to 64 QAM modulation. In contrast to a conventional 20 adaptive modulation controller, the switching threshold levels 94, 96, and 98 are here adaptively altered pursuant to the constrained optimization scheme. The enhanced LRI function provides a self-learning manner by which to select the switching

threshold levels which does not utilize expressions of throughput and the thresholds, nor does the manner make assumptions with respect to the operating environment of the communications. A class of learning techniques, namely, stochastic learning automata, is utilized.

In this approach, an automaton output is regarded as a set of switching threshold levels. That is, the thresholds are partitioned into a number of combinations, and the number of combinations are equal to the number of automaton output actions. The task of the automaton is to choose an action which gives a best performance function. The environment represents the operating environment of the modulation selector. The automaton uses a learning algorithm to update the output probability vector to govern a choice of switching thresholds. An LRI algorithm function successfully converges to the best action that gives the maximum TP. A manner is provided by which to estimate the FER, FPB, and TP values for the purposes of training up the automaton. And, an enhanced LRI function is provided which accepts a joint referee and performs optimization under a constraint.

Figure 4 illustrates a method, shown generally at 122 representative of the method of operation of the method of an embodiment of the present invention. The method dynamically

selects at least a first switching threshold used in selection of a modulation parameter.

First, and as indicated by the block 124, at least a first switching threshold is selected responsive to indications of a selected communication indicia associated with communication characteristics of a communication channel during a selected interval. The switching threshold is selected to at least satisfy a first performance criteria and to satisfy at least a second performance criteria. Then, and as indicated by the block 126, the modulation parameter is selected by which the data is operated upon by the first communication station prior to transmission upon the communication channel.

Thereby, a manner is provided by which to select a threshold level responsive to a constrained optimization scheme and, thereafter, select a modulation parameter responsive to values of the selected threshold level.

The previous descriptions are of preferred examples for implementing the invention, and the scope of the invention should not necessarily be limited by this description. The scope of the present invention is defined by the following claims.